V. *Electrostatic Capacity of Glass,* II., *and of Liquids.*

By J. Hopkinson, *M.A., D.Sc., F.R.S.*

I. Electrostatic Capacity of Glass.—II.

Received November 3,—Read December 16, 1880.

In 1877* I had the honour of presenting to the Royal Society the results of some determinations of the specific inductive capacity of glass, the results being obtained with comparatively low electromotive forces and periods of charge and discharge of sensible duration.

In 1878 Mr. Gordon† presented to the Royal Society results of experiments, some of them upon precisely similar glasses, by a quite different method, with much greater electromotive forces and with very short times of charge and discharge. Mr. Gordon's results and my own are compared in the following table :—

	Gordon.		Hopkinson, 1877.
	Christmas, 1877.	July and Aug., 1879.	
Double extra-dense flint	3·164	3·838	10·1
Extra-dense flint	3·053	3·621	
Light flint	3·013	3·443	6·85
Hard crown	3·108	3·310	

It is quite clear that such enormous differences cannot be due to mere errors of observation ; they must arise from a radical defect in one method or the other, or from some property of the material under investigation. I have now repeated my own experiments with greater battery power, and with a new key for effecting the connexions of the condensers, and have obtained substantially the same results as before.

Two hypotheses suggest themselves as to the physical properties of glasses which might, if true, account for the diversity of results :—(i.) In my own earlier experiments a considerable time elapsed, during which some have thought residual charge might flow from the glass condenser and go to swell the capacity determined. Sir W.

* Phil. Trans., 1878, Part I.

† Phil. Trans., 1879, Part I.

THOMSON had informed me that experiments had proved that the capacity of a good insulating glass is sensibly the same, whether the period of discharge be the ten- or twenty-thousandth of a second, or say one-quarter of a second. This statement has been verified. (ii.) It appeared plausible to suppose that specific inductive capacity of glass was not a constant, but was a function of the electromotive force—in other words, that the ratio $\frac{\text{charge of glass condenser}}{\text{difference of potential}}$ was less when the electromotive force was great than when it was small. This surmise gains some force from Dr. KERR's electro-optical results, which show that electrostatic and optical disturbance of a dielectric are not superposable. It has, however, been submitted to a direct test, with the result that, within the limits tried, specific inductive capacity *is* a constant, and that it is not possible that the discrepancy of experimental results can be thus explained. Finally, I have made a rough model of Mr. GORDON's five-plate balance, and used it to make determinations of specific inductive capacity.

Firstly, a brass plate was tried, and its capacity was found less than unity instead of infinite.

Secondly, by varying the distances of the plates of the balance from each other, different values of the specific inductive capacity of the same glass were obtained. In fact, it has been shown that the five-plate induction balance cannot be freely relied upon to give correct values of specific inductive capacity.

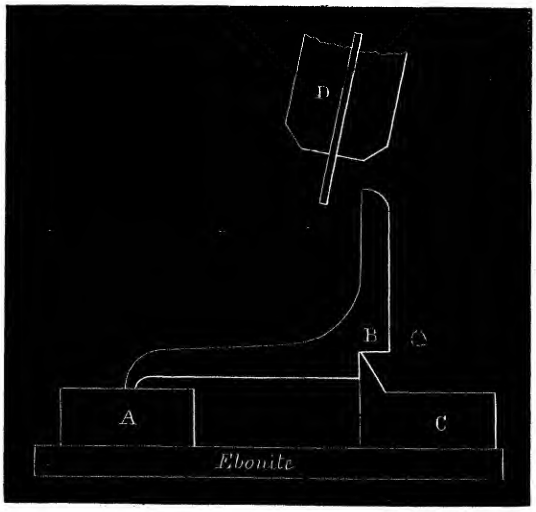
I conclude that the values I published in 1877 are substantially accurate, whether the period of discharge be $\frac{1}{20000}$ or $\frac{1}{2}$ second, whether the electromotive force be one volt per millimetre or 500 volts per millimetre, and that Mr. GORDON's different result is to be explained by a defect in the method he used.

(I.) *To prove that a condenser of well-insulated glass may be almost completely discharged in $\frac{1}{20000}$ second.*

For this experiment it is essential that the effect of conduction over the surface of the glass should be insensible. A jar, such as that used in Sir W. THOMSON's electrometer, is unsuitable. The proper form for the condenser is a flask with a thin body and a thick neck, filled with strong sulphuric acid to the neck. Such a flask of light flint glass was prepared, and was instantaneously discharged in the following manner:—The interior of the flask was connected to a metal block, A. Upon this block rests a little L-shaped metal piece, B, which can turn on a knife edge, C. A and C are carried on a block of ebonite, and are therefore insulated. D is a piece of metal connected to earth, and rigidly attached to the extremity of a pendulum. The pendulum is drawn aside and let go; the piece D strikes B and puts the jar to earth, and instantly afterwards breaks the contact with A, and drives away the piece B. In all cases the pendulum was drawn aside 45°, and in all the experiments but one mentioned below it made 93 half-oscillations per minute. The duration of the discharge was

determined by the following method, which I arranged for myself, unaware that a similar method had been used by Mr. SABINE.* A condenser of known capacity is connected to A through a known resistance; the condenser receives a known charge whilst connected to the electrometer; the piece B is struck by the pendulum, and the

Fig. 1.

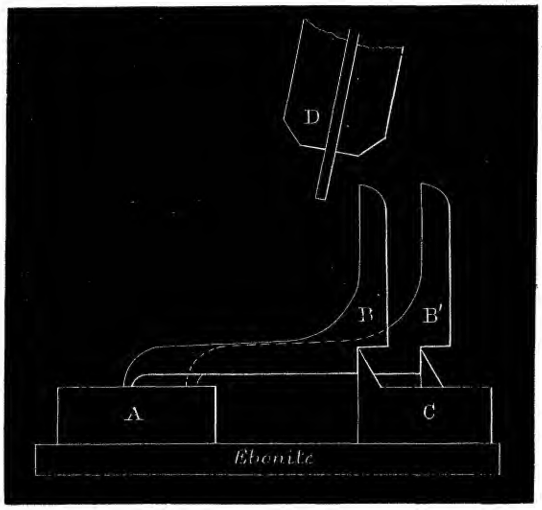


remaining charge is observed. Two experiments were made; in each the condenser was of tinfoil and paraffin, such as are used by Messrs. CLARK, MUIRHEAD, and Co. for telegraph purposes, and had a capacity of 0·29 microfarad. The resistances were respectively 512 ohms and 256 ohms. The results gave respectively duration of discharge 0 0000592 second and 0·0000595 second. We may take it that the duration of discharge was less than 0·00006 second. The condenser was now replaced by the flask. The flask was charged for some seconds from the battery, was insulated and discharged by the pendulum, and the remaining charge read off on the electrometer so soon as the image came to rest. In a first experiment the charge was from four elements (=444 divisions of the scale), and the charge remaining gave deflection 34 divisions. In a second experiment the charge was from eight elements (=888 divisions), and the remaining charge was 61 divisions. Even this small residual charge is largely due to the inductive action of the needle of the electrometer on the quadrant connected to the flask. To prove this, the experiment was varied by beginning with the quadrant separated from the flask, and only connecting these after discharge had been made. With eight battery elements, the remaining charge in the flask was found to be 25 divisions; with 20 elements, 61 divisions. From these experiments we may conclude that, if a flask of light flint glass be charged for some seconds and be discharged for 0·00006 second, the residual charge coming out in the next three or four seconds is certainly less than 3 per cent. of the original charge. It

* Philosophical Magazine, May, 1876.

was important to learn if this 3 per cent. was sensibly diminished if the time of discharge was somewhat increased. For this purpose the time of oscillation was increased, and the arrangement of piece B and knife-edge C was duplicated, so that the flask was twice discharged within an interval of about $\frac{1}{80}$ second between. The result was, with charge from eight elements and the flask initially connected to the

Fig. 2.



quadrant, a remaining charge of 61 divisions, exactly the same as when the discharge only lasted $\frac{1}{17000}$ second. I conclude that, with this glass, it matters not whether the discharge of the flask last $\frac{1}{17000}$ second or $\frac{1}{80}$ second; its capacity is the same. This is in precise accord with what Sir W. THOMSON told me before I began the experiments for my former paper.

(II.) *Determinations with the guard ring condenser.**

It has been suggested that my former results were liable to uncertainty from the small potentials used and from the comparatively long time of discharge. The main purpose of the present experiments has been to ascertain the force of the objections. As the principle of the method is the same as in the earlier paper, it is only needful to explain the alterations the apparatus have undergone.

The battery.—A chloride of silver battery of 1000 elements was constructed and very carefully insulated, both as regards cell from cell and tray from tray. Each tray contained 50 cells and the set of 20 trays was conveniently enclosed in a wooden case provided with suitable terminals. As my experience of the battery is but short

* The cost of the additional instruments used has been defrayed by a Royal Society Grant. The battery and some of the other instruments were made by Messrs. L. CLARK, MUIRHEAD, and Co., the remainder by Mr. GROVES.

I shall not now minutely describe its details, it is sufficient to say that by connecting its middle to earth two condensers can be charged to equal and opposite potentials of 500 elements.

The guard-ring condenser.—This is the instrument of my former experiments, with the switch removed and some slight improvements in mechanical detail. It is by no means perfect in workmanship, and the irregularities of the results now to be given are to be attributed to such imperfections. It was not worth while to make a new instrument, as, for any present interest, determinations of capacities of glasses, correct to 1 per cent., are as valuable as if they were absolutely accurate.

The sliding condensers.—Two sliding condensers were constructed possessing together a very considerable range of capacity. Each has a single scale and is used as before merely as a balance to the guard ring condenser, excepting in one experiment, the subject of the next section.

The switch.—The switch formerly used performed the following operations:—Initially, the quadrant of the electrometer was to earth, the guard ring and the plates of the guard ring condenser were connected to one pole of the battery, the sliding condenser to the other pole. On turning the handle the quadrant and the condensers were insulated; next, the charges of the condensers were mixed, the guard ring being put to earth at the same time; and, finally, the connected condensers were connected to the quadrant of the electrometer; they remained so connected until the handle of the switch was turned back into its first position. This instrument could not be used to

Fig. 3.

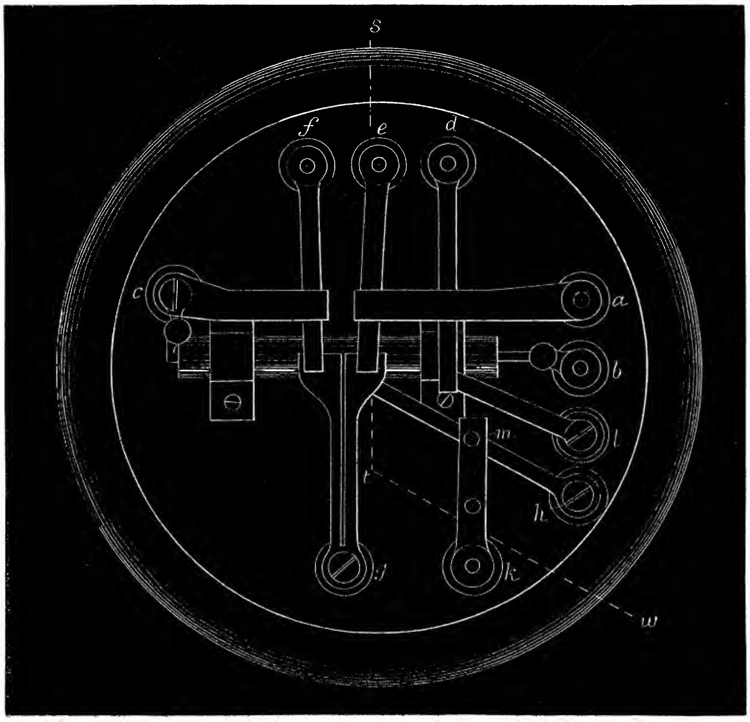
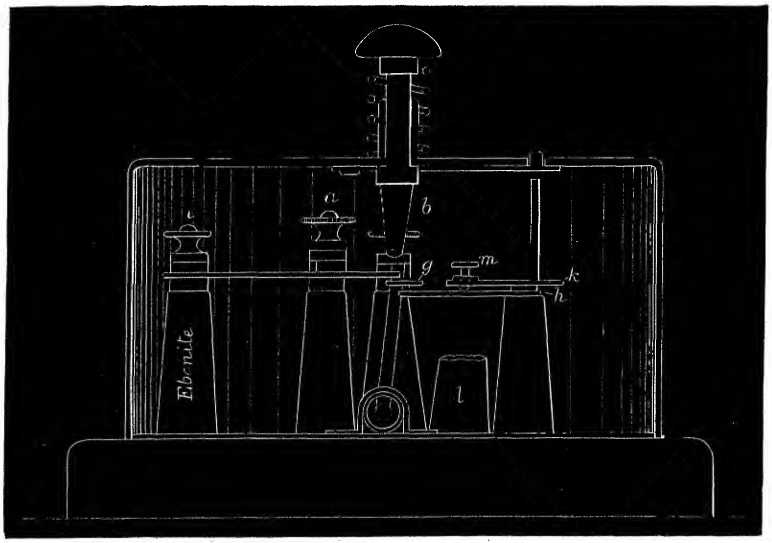


Fig. 4.



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determine capacities when the residual charge was great, as in the case of plate glass, and was unsatisfactory to anyone who held that flint glass condensers discharged very much more in a time comparable with one second than in a minute fraction of a second. The new switch was arranged to effect the further operation of breaking contact between the condensers and the quadrant immediately after the contact was made. It is also arranged for much higher insulation, the old switch being quite useless for the greater battery power used.

a, c are stiff insulated horizontal contact bars connected to the two poles of the battery. d, e, f are insulated springs normally touching a and c on the under side, d is connected by a wire to the guard ring, e to the plate of guard ring condenser, f to the sliding condenser. b is an insulated binding screw connected with c for the purpose of more conveniently introducing the battery wire. l is a spring connected to earth. k is a stiff insulated piece, carrying an adjustable point m, normally in contact with the upper side of the insulated spring h. From k a wire leads to the quadrant of the electrometer. k can at any moment be put to earth by a spring key. The insulated spring g has its end between e, f, and h, and is normally in contact with neither. The springs d, e, f can be simultaneously bent downwards by an insulated plunger. When this plunger is struck downwards we have the following operations effected in a fraction of a second—

1°. $\begin{cases} d \text{ and } e \text{ are in contact with } a. \\ f \text{ in contact with } c. \end{cases}$

2°. d, e, and f insulated.

3°. $\begin{cases} d \text{ connected to } l. \\ e, f, \text{ and } g \text{ connected together.} \end{cases}$

4°. *e*, *f*, *g*, *h*, *k* connected together.
5°. Connection of *k* and *h* broken.

In other words we have—

1°. Initially $\left\{\begin{array}{l}\text{Guard ring.}\\ \text{Guard ring condenser plate, and}\\ \text{One pole of battery.}\end{array}\right.$
$\left\{\begin{array}{l}\text{Sliding condenser.}\\ \text{Other pole of battery.}\end{array}\right.$
2°. All condensers insulated.
3°. $\left\{\begin{array}{l}\text{Guard ring.}\\ \text{Earth.}\end{array}\right.$
$\left\{\begin{array}{l}\text{Guard ring condenser plate.}\\ \text{Sliding condenser.}\end{array}\right\}$ Mixing of charges.
4°. Mixed charges to electrometer.
5°. Electrometer insulated.

The whole switch, binding screws and all, is covered with a brass cover connected to earth and provided with apertures for the connecting wires. The ebonite legs which carry the pieces *a*, *b*, *c*, *d*, *e* *f*, *g*, *k* are attached to a brass base plate, so that if any leakage occur from *a*, *b*, *c*, *d*, *e*, or *f*, it shall be to earth and not to the electrometer. The connecting wires are insulated with gutta-percha, covered with a metallic tape as an induction shield, this tape being of course connected to earth.

The mode of experiment was substantially as before. A glass plate was introduced in the guard ring condenser, and the sliding condenser adjusted till the capacities were equal; the glass plate was removed and the guard ring condenser, with air as its only dielectric, was adjusted till its capacity was equal to that of the sliding condenser. In every case the battery was reversed and the mean taken.

The following tables give the results obtained:—

All measures are given in terms of turns of the micrometer screw of the guard ring condenser, of which there are 25 to the inch.

Column I. gives the circumstances of the particular experiment.

Column II. the distance between the plates of the condenser with glass in.

Column III. the same distance with air only when the capacity is the same as in II.

Column IV. the thickness of air plate equivalent to glass plate.

Column V. resulting value of K.

DOUBLE extra-dense flint. Density, 4·5. Thickness of plate, 24·27.

I.	II.	III.	IV.	V.
200 elements used, 100 to each condenser, glass in contact with both plates	24·27	2·48	2·48	9·78
1000 elements, contact with both plates	24·27	2·48	2·48	9·78
1000 elements, resting on lower plate, space between glass and upper plate	24·69	2·865	2·445	9·92
Ditto ditto ditto . . .	25·19	3·36	2·44	9·94
Ditto ditto ditto . . .	25·39	3·57	2·45	9·90
Glass separated from lower plate by three small pieces of ebonite also separated from upper plate.	25·19	3·36	2·44	9·94

Mean of last five experiments, K=9·896.
Result formerly published, 10·1.

DENSE flint. Density, 3·66. Thickness of plate, 16·57.

I.	II.	III.	IV.	V.
Glass in contact with both plates, 400 elements	16·57	2·265	2·265	7·31
Glass in contact with both plates, 1000 elements	16·57	2·265	2·265	7·31
Glass resting on lower plate, 1000 elements	17·19	2·85	2·23	7·43
Ditto ditto	17·69	3·36	2·24	7·39

Mean of last three experiments, K=7·376.
Result formerly published, 7·4.

LIGHT flint. Density, 3·2. Thickness of plate, 15·04.

I.	II.	III.	IV.	V.
Glass in contact with both plates, 1000 elements	15·04	2·215	2·215	6·79
Glass resting on lower plate, 1000 elements	15·29	2·505	2·255	6·67
Ditto ditto	15·69	2·865	2·215	6·79
Ditto ditto	16·19	3·42	2·27	6·62

Mean value of K=6·72.
Results formerly published, 6·89 and 6·76=6·83.

LIGHT flint. Thickness, 10·75.

I.	II.	III.	IV.	V.
Contact with both plates, 1000 elements	10·75	1·61	1·61	6·67
Resting on lower plate	11·19	2·035	1·595	6·74
Ditto	11·69	2·555	1·615	6·65

Mean value of K=6·69.
Result formerly published, 6·90.
Mean result for light flint, 6·72.
Mean formerly published, 6·85.

VERY light flint. Density, 2·87. Thickness, 12·70.

I.	II.	III.	IV.	V.
Glass in contact with both plates, 400 elements	12·7	1·915	1·915	6·63
Glass in contact with both plates, 1000 elements	12·7	1·915	1·915	6·63
Glass in contact with lower plate only, 1000 elements	12·99	2·215	1·925	6·59
Ditto ditto ditto	13·39	2·61	1·920	6·61

Mean of last three, K=6·61.
Result formerly published, 6·57.

HARD crown. Density, 2·485. Thickness, 11·62.

I.	II.	III.	IV.	V.
Glass in contact with both plates, 1000 elements	11·62	1·675	1·675	6·93
Glass in contact with lower plate only, 1000 elements	11·70	1·74	1·66	7·0
Ditto ditto ditto	11·90	1·945	1·665	6·98
Ditto ditto ditto	12·30	2·255	1·675	6·93

Mean value of K=6·96.

PLATE glass. Thickness, 6·52.

I.	II.	III.	IV.	V.
Glass in contact with lower plate only, 400 elements	7·70	1·95	0·77	8·47
Ditto ditto 1000 elements	7·70	1·95	0·77	8·47
Ditto ditto ditto	7·40	1·665	0·785	8·43

Mean value of K=8·45.

REMARK.—On account of the small thickness of the equivalent plate of air, $\frac{1}{30}$ inch, this result is subject to a greater probable error than the others. No inconvenience or uncertainty was experienced from the effect of residual charge. If the screw (*m*, figs. 3, 4, pp. 359, 360) be lowered so that contact with the electrometer is not broken, observation becomes at once impossible.

These results show that my former experiments require no material correction, except in the case of plate glass, for which an accurate experiment was formerly impossible. They also show that electrostatic capacity does not depend on electromotive force up to 200 volts per centimetre for double extra-dense flint, and a somewhat higher electromotive force for the other glasses. It is desirable to show that the same is true for a wider range.

PARAFFIN. Thickness, 20·19.

I.	II.	III.	IV.
Resting on lower	23·82	12·42	8·79
Ditto	22·71	11·32	8·80
Ditto	21·37	9·96	8·78
Contact with both . . .	20·19	8·78	8·78

Mean value of K = 2·29.

In this case the guard ring condenser was always charged with 700 elements, the slide with 300 in order that the same sliding condenser might be used.

BOLTZMANN gives 2·32 for paraffin for short times of discharge.

(III.) *To show that* K *is a constant, as is generally assumed.*

Dr. DE LA RUE very kindly allowed me to try a few preliminary experiments last February with his great chloride of silver battery. A flask of extra-dense flint glass was used, insulated with sulphuric acid precisely as in my experiments on residual charge. The comparison was made with a large sliding condenser having a scale graduated in millimetres. Taking one division of the scale (= about 0·0000026 microfarad) as a temporary unit of capacity, I found it impossible to say whether the capacity of the flask was greater or less than 390 divisions, whether the charge in each condenser was 20 elements or 1800 elements. Subsequently a similar experiment was tried with my own battery and a flask of light flint, with the following results, each being the mean of four readings :—

Charge to each condenser in Ag.Cl. elements.	Capacity in millim. divisions of sliding condenser.
10	273·75
100	274·00
200	273·75
300	274·5
400	273·0
500	273·5

The mean of these is 273·75, and the greatest variation from the mean 0·28 per cent.

The conclusion has some considerable importance, for some conceivable molecular theories of specific inductive capacities would lead to the result that capacity would be less when the charge became very great, as is actually the case with the magnetic permeability of iron (*vide* MAXWELL, vol. ii., chapter vi.).

The flasks tried are about 1 millim. thick. I intend to try a very thin glass bulb, testing it to destruction.

[In order to extend the limits of this test, a thin bulb 29 millims. diameter was blown on a piece of thermometer tube and its capacity compared with the sliding condenser with varying charge, as follows :—

100 battery elements to each condenser, capacity of bulb was 297 scale divisions.

300 elements, capacity=297 divisions.

500 elements, capacity=$297\frac{1}{2}$ divisions.

The bulb was afterwards broken and the thickness of the fragments measured; they ranged from 0·05 to 0·15 millim., the major portion being about 0·1 millim. We may conclude with confidence that the value of K for the glass tested continues constant up to 5000 volts per millimeter.—Dec. 9, 1880.]

An experiment was subsequently tried to ascertain if specific inductive capacity varied with the temperature of the dielectric. Accurate results could not be obtained, owing to the expansion of the acid, causing it to rise in the neck of the flask. The result of the single experiment tried was, however, that the flask at 14° C. had a capacity equal to 275 divisions of the sliding condenser; at 60° C. it was equal to 280 divisions. Having regard to the increase of capacity due both to the expansion of the glass (which may safely be neglected) and to the expansion of the acid (which is material), we can only conclude that the capacity of glasses certainly does not change rapidly with temperature—that consideration of temperature cannot be expected to reconcile Professor MAXWELL'S theory with the results of experiment.

I have repeated the temperature experiment with greater care. The flask was cleansed, filled a little short of the shoulder with acid, and arranged for heating and testing as before. In order to avoid the effect of rising of the level of the acid from expansion, the flask was heated to its highest temperature before any observation.

It was assumed that on cooling the surface of the flask would continue to conduct to the level at which the acid had been.

The following table gives the results of the experiment:—

Temperature Centigrade.	Capacity.	
81°	$269\frac{1}{2}$	11th Nov.
48	266	,,
27	$263\frac{1}{2}$	,,
12	262	12th Nov.
$39\frac{1}{2}$	$266\frac{1}{2}$	,,
$67\frac{1}{2}$	$268\frac{1}{2}$	,,
83	$271\frac{1}{2}$	,,
60	268	,,
$50\frac{1}{2}$	267	,,
13	264	13th Nov.

We may conclude, I think safely, that the specific inductive capacity of light flint does increase slightly, but that the increase from 12° to 83° does not exceed $2\frac{1}{2}$ per cent. The conductivity of the same glass* increases about 100-fold between the same temperature, and the residual charge also increases greatly.

(IV.) *Examination of the method of the five-plate induction balance.*

The theoretical accuracy of this method rests on the assumption that the distance between the plates may be considered small in comparison with their diameter. When this condition is not sufficiently considered, it is easy to see that it is not likely that correct results will in all cases be obtained, for suppose that in lieu of the plate of glass a thin sheet of metal of considerable size is interposed between the fourth and fifth plates of the balance, it ought to be needful to withdraw the fifth plate by an amount equal to the thickness of the sheet. One can apprehend that it will be actually necessary to push it in, but to an extent which it would not be easy to calculate.

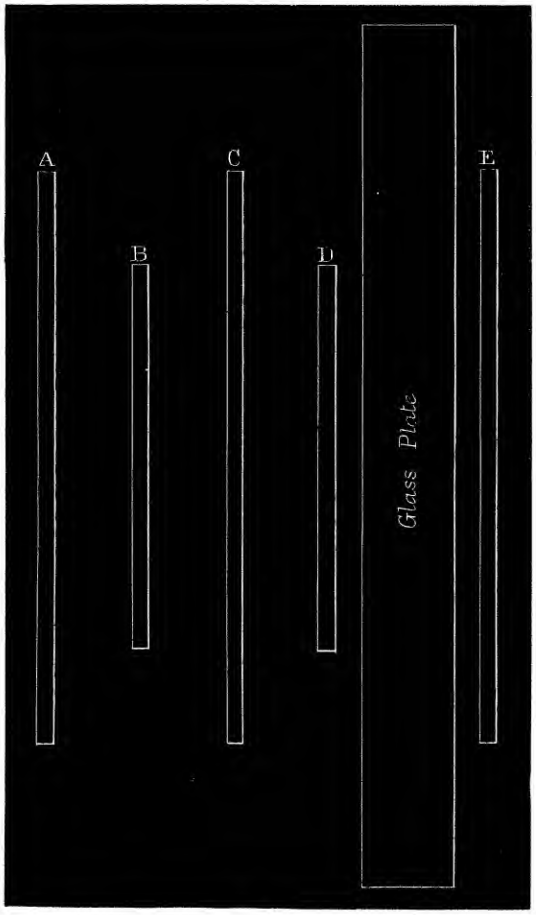
Some doubt is also thrown upon the practical accuracy of the method by the fact that Mr. GORDON has arrived at the very unexpected result that the specific inductive capacities of glasses change with the lapse of time.

In order to satisfy myself on the point I had a rough model of a five-plate induction balance made. The instrument is far too rough to give minutely accurate results if the method were good, but I believe it is sufficient to show rapidly that it cannot be used with safety. The insulation was not perfect, and no attempt was made to enclose the instrument or shield the connexions from casual inductive action. The plates are all 4 millims. thick; they are, as in Mr. GORDON's apparatus, 6 and 4 inches diameter. Each plate is suspended in a vertical plane by two rods and hooks from

* "Residual Charge of the Leyden Jar," Phil. Trans., 1877.

two of a set of four horizontal rods of varnished glass. The plates can thus be placed parallel to each other at any distance apart that may be desired. The distance between the plates was measured by a pair of common callipers and a millimeter rule to the nearest $\frac{1}{4}$ millimeter. For convenience, let the plates be named A, B, C, D, E, as

Fig. 5.



Half full size.

in the accompanying diagram. In a first experiment B and D were respectively connected to the quadrants of an electrometer of which the jar was charged in the usual way. A and E were connected to one pole of a battery of 20 AgCl elements, C to the other pole through an ordinary electrometer reversing key, E was adjusted till the disturbance of the image was a minimum, when the key was reversed. This method was unsatisfactory, probably because in the act of reversing all the plates A, C, E were momentarily connected to one of the poles, and also because the insulation of the plates B, D was imperfect. The experiments, however, sufficed to prove beyond doubt that the instrument gave diminishing values to the specific inductive capacity of glass, as the distance of the five plates from each other was increased from 12 millims. to 32 millims., also that it gave values less than unity for the specific inductive capacity of brass in the form of a plate 3·5 millims. thick. More satisfactory

working was attained by approximating, so far as my instruments admitted, to the methods of Mr. GORDON. B and D were, as before, connected to the quadrants, C was connected to the interior of the jar and to one pole of an ordinary induction coil; A and E to the case of the instrument and to the other pole of the induction coil. The plate E was adjusted till the working of the coil caused no deflection of the image on the scale. In each case the plate examined was placed approximately half-way between D and E. The following table gives results of a plate of double extra-dense flint 24·75 millims. thick and 235 millims. diameter, and on a plate of brass 3·5 millims. thick and 242 millims. diameter.

Column I. gives the air-space between the plates AB, BC, or CD.

Column II. the air-space DE (a_1) when no dielectric plate was present.

Column III. the distance DE (a_2) when a dielectric was introduced.

Column IV. the value of the difference $b-(a_2-a_1)$, b being the thickness of the plate, which ought to be constant for each plate.

Column V. the specific inductive capacity $=\frac{b}{b-(a_2-a_1)}$.

DOUBLE extra dense flint, 24·75 m.m. thick.

I.	II.	III.	IV.	V.
5	$5\frac{1}{4}$	27	3	8·25
8	$8\frac{1}{4}$	$30\frac{1}{4}$	$2\frac{3}{4}$	9·0
12	$11\frac{3}{4}$	$31\frac{3}{4}$	$4\frac{3}{4}$	5·21
18	21	$37\frac{1}{4}$	$8\frac{1}{2}$	2·91
25	$32\frac{1}{2}$	$43\frac{3}{4}$	$13\frac{1}{2}$	1·83
32	$44\frac{1}{2}$	$49\frac{1}{2}$	$19\frac{3}{4}$	1·25

True value of K=9·896.

BRASS plate, 3·5 m.m. thick.

I.	II.	III.	IV.	V.
5	4·5	6·75	1·25	2·8
8	8·0	6·25	5·25	0·66
12	11·25	10·0	4·75	0·73
32	44·5	16·5	31·5	0·11

True value of K= ∞^{ty}.

Inspection of the column IV. shows how impossible it is to attribute the variations of K to any mere error of observation even with the roughest appliances. Column V. demands no comment.

II. Electrostatic Capacity of Liquids.*

Received January 6,—Read January 27, 1881.

The number of substances suitable for an exact test of Professor Maxwell's electromagnetic theory of light is comparatively limited. Amongst solids, besides glass, Iceland spar, fluor spar, and quartz have been examined by Romich and Nowak,† giving results for specific inductive capacity much in excess of the square of the refractive index. On the other hand, the same observers, with Boltzmann, obtain for sulphur a value of the capacity in reasonable accord with theory.

On liquids the only satisfactory experiments are those of Silow‡ on turpentine and petroleum oil, in which the capacity is precisely equal to the square of the refractive index for long waves.

Silow finally obtains for long waves and capacity—

	μ_∞.	$\sqrt{K}$.
Turpentine	1·461	1·468
Petroleum I.	1·422	1·439
Petroleum II.	1·431	1·428
Benzol	1·482	1·483

A comparison of the whole of the substances which have been examined indicates the generalisation that bodies similar in chemical composition to salts, compounds of an acid, or acids and bases, have capacities much greater than the square of the refractive index, whilst hydrocarbons, such as paraffin and turpentine, cannot be said with certainty to differ from theory one way or the other. It seemed desirable to test this conclusion by experiments on animal and vegetable oils and on other paraffins. It was probable that the compounds of fatty acids and glycerine would have high capacities.

Samples were tested of colza oil, linseed oil, neatsfoot oil, sperm oil, olive oil, castor oil, turpentine, bisulphide of carbon, caoutchoucine, the paraffin actually in use for the electrometer lamp, and three widely different mineral oils kindly given to me by Mr. F. Field, F.R.S., to whom I am indebted for the boiling points given below.

The method of experiment was very simple. The sample was first roughly tested for insulation. It was found that it was useless to attempt the samples of colza or linseed oils, of caoutchoucine, or of bisulphide of carbon, but that the rest had sufficient insulation for the tolerably rapid method I was able to use.

The fluid condenser consisted of a double cylinder to contain the fluid, in which an

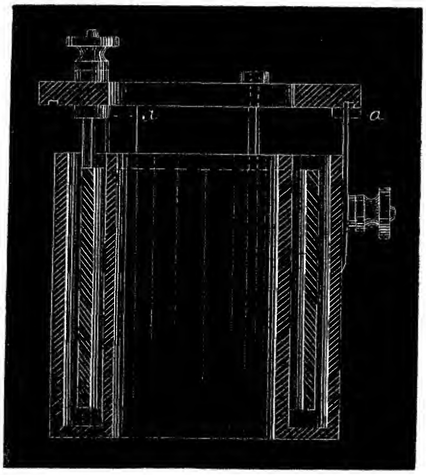
* The abstract of this paper is published in the Proceedings under the title "Dielectric Capacity of Liquids."

† Wiener Sitzb. lxx., part ii., p. 380.

‡ Pogg. Ann., 156, 1875, p. 389, and 158, 1876, p. 313.

insulated cylinder could hang; three brass rods suspended the latter from an ebonite ring which rested on three legs rising from the outer cylinder of the annular vessel. The position of the insulated cylinder was geometrically determined by three brass stops (a, a, a) which abutted against the legs which carried the ring, six points being thus fixed. A dummy ebonite ring with three brass rods, but without the cylinder, was provided for the purpose of determining the capacity of all parts and connexions not immersed in fluid.

Fig. 6.



Half full size.

The condenser was balanced against a sliding condenser, first with air and then with fluid.

The key which was used for experiments on plates was used here also, leaving the piece connected to the guard ring idle.

The capacity of the sliding condenser was first tested with the result that to the reading of the slide 82·2 must be added to obtain the capacity in terms of the millimeter divisions of the scale. The capacity of the fluid condenser empty, with its connexions, was 106·5 divisions. The capacity of the dummy and connexions was 7·7, so that the nett capacity of the fluid condenser was 98·8. In all cases 1000 AgCl elements were tried, these being divided between the two condensers.

The following tables give the results obtained:—

Column I. is the number of elements charging the fluid condenser, the complement being used on the sliding condenser.

Column II. the reading of the slide plus 82·2 when a balance was obtained; this is the mean of two readings when the fluid condenser was respectively charged positive and negative.

Column III. is the capacity calculated from the experiment.

Petroleum spirit. Boiling point, 159°.

I.	II.	III.
400	133·2	1·94
500	196·7	1·91
600	294·7	1·91

Mean value of K=1·92.

Petroleum oil (FIELD'S). Boiling point, 310°.

I.	II.	III.
350	114·2	2·07
400	141·2	2·06
500	212·2	2·07

Mean value of K=2·07.

Petroleum oil (*common*).

I.	II.	III.
400	144·2	2·11
500	214·2	2·09
600	321·2	2·09

Mean value of K=2·10.

Ozokerit lubricating oil. Boiling point, 430°.

Two determinations of this oil were made some days apart; at the time of the first determination the oil was slightly turbid. In the interval before determining the refractive index the upper portion became clear, the heavier particles having settled down. The capacity of the clear oil was then determined, and the results are given in the second table. It is possible that if the oil remain quiescent for a longer time a further reduction may be observed.

First experiment.

I.	II.	III.
400	149·2	2·19
500	223·2	2·18
600	334·7	2·18

Mean value of K=2·18.

Second experiment.

I.	II.	III.
400	146·2	2·14
500	217·7	2·12
600	327·7	2·13

Mean value of K=2·13.

Olive oil.

I.	II.	III.
300	137·7	3·17
400	213·7	3·16
500	319·2	3·15

Mean value of K=3·16.

Castor oil.

I.	II.	III.
250	160·2	4·78
300	306·2	4·79
400	319·2	4·76

Mean value of K=4·78.

Sperm oil.

I.	II.	III.
300	132·2	3·04
400	202·7	3·00
500	306·7	3·02

Mean value of K=3·02.

Neatsfoot oil.

I.	II.	III.
300	134·2	3·09
400	206·7	3·06
500	311·2	3·07

Mean value of K=3·07.

Turpentine.

A satisfactory determination for turpentine was not obtained. The turpentine seemed to act on the material of the vessel. After being in the condenser a short time its insulation was much reduced. When the charge had a potential of about 600 elements the condenser discharged itself disruptively through the turpentine. However, with a charge of 100 elements on each condenser a balance was obtained at 228·2, indicating a specific inductive capacity 2·23.

The refractive indices were determined *from the same samples* as the capacities in the usual way by the minimum deviation of a fluid prism. The spectrometer was the same I had previously used for experiments on glass (Proc. Roy. Soc., 1877). The observations were made for the hydrogen lines and the sodium lines, from these the

index for long waves was calculated by the formula $a+\frac{b}{\lambda^2}$. The results are given in the following table :—

	μC.	μD.	μF.	μG.	$\mu\infty$.	Temperature.
Petroleum spirit	1·3952	1·3974	1·4024	1·4065	1·3865	12·75
Petroleum oil (FIELD'S) . . .	1·4520	1·4547	1·4614	1 4670	1·4406	13·0
Petroleum oil (common) . .	1·4525	1·4551	1·4615	1·4670	1·4416	13·0
Ozokerit lubricating oil. . .	1·4558	1·4585	1·4653	. .	1·4443	13·0
Turpentine	1·4709	1·4738	1·4811	1·4871	1·4586	13·25
Castor oil	1·4785	1·4811	1·4877	1·4931	1·4674	13·5
Sperm oil	1·4724	1·4749	1·4818	. .	1·4611	13·75
Olive oil	1·4710	1·4737	1·4803	. .	1·4598	14·0
Neatsfoot oil	1·4673	1 4696	. .	. .	1·4578	14·0

In the following table is given a synoptic view of the comparison of $\mu\infty^2$ and K :—

	$\mu\infty$.	$\mu\infty^2$.	K.
Petroleum spirit	1·3865	1·922	1·92
Petroleum oil (FIELD'S). . .	1·4406	2·075	2·07
Petroleum oil (common) . .	1·4416	2·078	2·10
Ozokerit lubricating oil . . .	1·4443	2·086	2·13
Turpentine	1·4586	2·128	2·23
Castor oil	1·4674	2·153	4·78
Sperm oil	1·4611	2·135	3·02
Olive oil	1·4598	2·131	3·16
Neatsfoot oil	1·4578	2·125	3·07

A glance shows that vegetable and animal oils do not agree with MAXWELL'S theory, the hydrocarbon oils do. It must, however, never be forgotten that the time of disturbance in the actual optical experiment is many thousands of million times as short as in the fastest electrical experiment even when the condenser is charged or discharged for only the $\frac{1}{20000}$ second.